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Vision Based Robot Experiment: Measurement of Path Related Characteristics

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Abstract**—** In this paper, a vision based system has been used for controlling an industrial 3P Cartesian robot. The vision system will recognize the target and control the robot by obtaining images from environment and processing them. At the first stage, images from environment are changed to a grayscale mode then it can diverse and identify objects and noises by using a threshold objects which are stored in different frames and then the main object will be recognized. This will control the robot to achieve the target. A vision system can be an appropriate tool for measuring errors of a robot in a situation where the experimental test is conducted for a 3P robot. Finally, the international standard ANSI/RIA R15.05-2 is used for evaluating the path-related characteristics of the robot. To evaluate the performance of the proposed method experimental test is carried out.

Keywords**—** Robot, Vision, Experiment, Standard.

I. INTRODUCTION

THE main purpose of this article is the development and application of vision based system for controlling industrial robots and performing laboratory tests based on path-related performance characteristic tests. It is required to be well-informed about robot, and its components software and hardware of the robot which is controlled by a camera for using vision based system, then we can obtain enough information about camera and terms and principles of xerography in order to get perspicuous images for analysing them.

Nowadays for imagery of robot actions to human beings, we need some possibilities like human eyes in order to make the robot to be able to surround all its environment. Thus various kinds of cameras are used for controlling robot. The camera takes images and sends them to the brain of the machine for analyzing the tasks. After all, the robot recognizes to do the required motion. We should obtain complete information about camera and its terms and essentials to overcome all of these operations.

Primary systems of visual servoing refer to 1980, which processing in visual controlling was very low, but after a short time many researches have been done in this field. J. Muligan used this system for controlling spade of louder machines, and by processing the pictures specially edge detection, which are the most usable styles for specifying the positions and controlling machine's arm [1]. T. Nakamura studied on an inexpensive remote robot which has used vision system in soccer robots [2]. Also, many studies have been done about bin picking for example Ovidiuo Ghita [3]. We can mention many different methods for controlling and positioning of a robot in article of B. Vikramaditya. That term is one of the important items about vision system [4]. Gregory Flandin explained about the usage of the camera's in eye-in-hand/eye-to-hand mode for controlling robots [5]. Visual system has been used for increasing the precision of robot. N. J. Ferier studied on this matter for identification of the target. [6] Andrea Banarini used an omni directional visual sensor in his mobile robot for quick identifying of environment objects. [7] Thomas M. Breual used vision system and statistic equation for identifying a special thing in an image [8]. One of the most important matters in image processing is edge-detection which is usually done by software. A. Hajson performed this matter in hardware by using VLSI. Although processing has been done very fast but it maximized the expenses of system and also flexibility of hardware was lower than software systems [9]. Robotic systems are becoming more compressed and cheaper and applicable before undefined cases of past and so are vision systems. SVM1 (Small Vision Module) is a small and cheap unit for processing images, which is a basic tool for usage of vision system in computer. Kurt Konolige explained software and hardware of a SVM construction [10].

In this article, first, the structure and components of 3P Cartesian robots are explained and the used interface board of system is described, then the whole system and its software and hardware are explained. ISO 9283 and ANSI/RIA R15.05.2 are used to determine path related parameters. Finally, an experiment involving a 3P Cartesian robot is considered and analysed in a situation where the robot is required to follow a specified trajectory.

II. HARDWARE OF 3P ROBOT

The electronic and hardware sections of this robot consist of seven parts as follows:

1- Power Supply
2- Servo DC Motors
3- Encoder
4- Drivers or Motor's Amplifier
5- Control Board of 3P Robot Axis
6- Proximity Switches and Microswitches

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7- Interface Boards

Meanwhile the robot contains of three prismatic joints and will be scheduled for many tasks. For more information about designing of software and controlling of this robot refer to [11-12].

III. INTERFACE BOARD GPIO324-E

An interface card is needed to connect the visual system to robot system in order to send and receive the information. It should be noted that operating system of robot is different from operating system of visual system. Because, the driver of the servo DC motor is working under DOS, but camera's driver is under Windows system. This board is a multifunction digital input/output card for IBM/AT/XT/PC or compatible computers. It offers the three most desired control functions: digital input, digital output and timer/counter.

IV. DESCRIPTION OF THE SYSTEM

Fig. 1 3P Cartesian Robot

In order to operate a visual system for controlling a robot, some facilities are needed which may be different base on their usage's. Camera is the main hardware of visual system, and in different visual system the only similar part is camera. In this system the following components are needed. (Fig. 1)

1- 3P Robot
2- System of Controlling 3P Robot
3- System of Image Processing
4- Camera
5- Two Interface Board for Controlling the Systems
6- Connecting Cable

V. METHOD OF OPERATING THE WHOLE SYSTEM

We should prepare the robot system and the vision system and then control program. If the aim is getting object by end effector, then the vision system takes an image from environment initially. That image will be processed and if the main object was recognized in that, image and processing was successful then it will consider position. So, the necessary displacement of x, y, z for moving end effector will be sent from vision system to robot system by using interface board. The related program of robot will get information and move the robot. Meanwhile the vision system waits for information from the robot system in order to be sure about the end of robot function and its stabilization. In other word, after robot task and it's stabling, a signal is sent to the vision system to continue its operation. This will be continued till the target exactly places in the middle of the image.

VI. CONTROLLING SOFTWARE OF VISION SYSTEM

This software is considered for controlling vision system by using visual C++6. The applied algorithm of this software like thresholding and segmentation and etc. is similar to 3P robot software [13]. So, some algorithm are changed for getting proper result, because using that algorithm in experimental tests had problems. For example in the experiment our images from environment aren't ideal image, therefore some times we had many noise in image and it was difficult to remove all of those noise from image.

VII. CONTROLLING SOFTWARE OF ROBOT SYSTEM

The source related to controlling robot software is written by C under MSDOS. In this program you face with two base addresses. 300 Hex base address, which refer to base address of interface board and 240 Hex address refers to base address of controlling robot actuator. We use initialization of control word for appointing the position of registers (input or output), here 0x99 (10011001) that A and C registers are input ports and B register is output port and system is initialized in 0 mode.

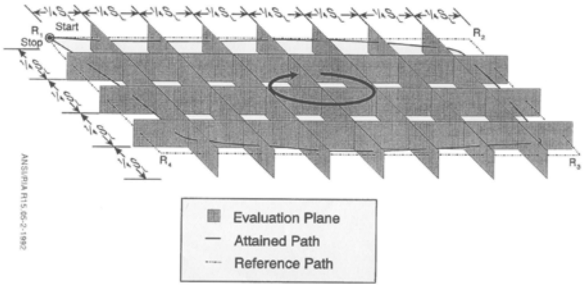

Fig. 2 Reference rectangular path and attained path in evaluation plane

VIII. EXPERIMENTAL TESTS

In this Section, we will control robot by vision system and measure the rate of errors. Initially, the vision system will be tested which is assigned for taking images and reaching to the object. Before testing the vision system on robot, we test on camera in order to get efficiency of different terms of light on an image and inform about the process of objects recognition. By some tests we can specify the robot's errors. Standard for robots test platform are used to specify the error rate as shown in Fig. 2 [14]. Path accuracy evaluation points for both circle and rectangular references path are conducted (Fig. 3).

IX. PROCESSING OF IMAGES IN DIFFERENT TERM OF ENVIRONMENT LIGHT

Two similar images in different terms of light will have different results. Possibility of identifying an object in an image is in high range and vice versa. Here the range of threshold is determined (Figs. 4 a, b).

X. CONTROLLING ROBOT BY CAMERA

When there is an image and the main object is recognized, number of pixels between object and the place of its stand can be calculated through image. After giving this number to robot control system for robot moving and prompt reaching to objects. Calculating pulse number bases on pixel number for each 3P robot x, y, z axes is different. The difference is the result of gearwheel sizes and each one is different from the other. Traversing an equal rate for each axis needs different pulses. These pulses should be obtained by try and error, of course because of robot mechanical limitation, it may not be able to transmit the robot exactly toward the target (Fig. 3).

XI. PERFORMING STANDARD TESTS ON 3P ROBOT

Path accuracy evaluation points for both rectangular and circle reference path is carried out based on ANSI/RIA R15.05-2 standard path as shown in Figs. 5 and 6.

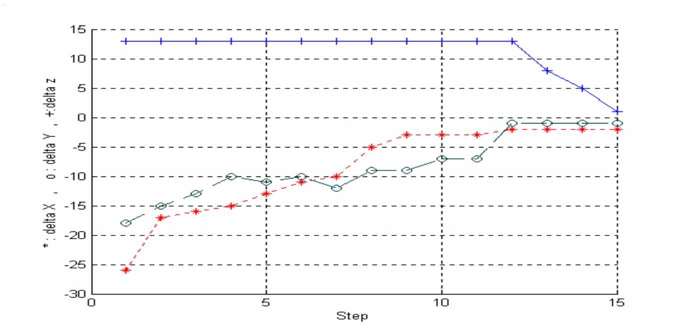

Fig. 3 The diagram of error correction using vision (per pixel)

XII. RECTANGULAR AND CIRCLE REFERENCE PATH

In this standard, a rectangular path should evaluate at least 20 points of robot's actual path and reference path as shown in Fig. 5. Similarly, we should use at least 12 points for circle path (Fig. 6).

XIII. MEASUREMENT OF FOM (FIGURE OF MERIT)

FOM is attained by finding common space of attained path in the calculation of the path accuracy. FOM's is simplified by finding the intersection of the attained path in the two dimensional evaluation plane. The resulting two-dimensional path accuracy values represent the error between any given attained path and corresponding reference path. This standard will quantify path accuracy using the following two calculated figures of merit (FOM), maximum deviation and average deviation.

XIV. MAXIMUM DEVIATION OF AC

AC is the maximum distance between any given attained path and corresponding reference path. This deviation could occur at any one of the measured evaluation points for a minimum of ten measurement cycles, as follows.

$$AC=\max_{i=1}^{n}\max_{j=1}^{m}\sqrt{(u_{a_{ij}}-u_{r_j})^2+(v_{a_{ij}}-v_{r_j})^2} \qquad (1)$$

where, $(v_{a_{ij}}, u_{a_{ij}})$ and (v_{r_j}, u_{r_j}) correspond to the coordinates of the attained path and reference path on the evaluation plane, respectively. Parameter (n) specifies repeating and m parameter is number of points on the evaluation plane.

XV. AVERAGE DEVIATION $\overline{AC}$

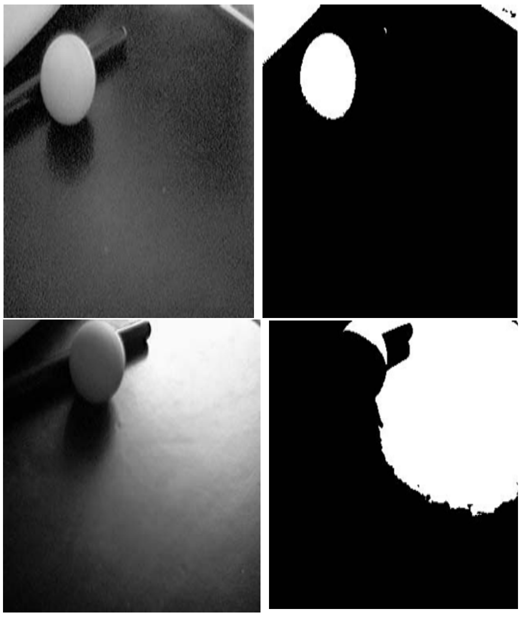

Fig. 4 (a) The diagram of error correction using vision (per pixel) (b) Grayscale and Threshold of image in good light condition

$\overline{AC}$ is the average of the distance between any given attained path and the corresponding reference path as follows:

$$\overline{AC}=\frac{1}{m}\sum_{j=1}^{m}\sqrt{(u_{a_j}-u_{r_j})^2+(v_{a_j}-v_{r_j})^2} \qquad (2)$$

$u_{a_{ij}}, v_{a_{ij}}$ correspond to the coordinates of the barycenter path which are defined as:

$$\bar{u}_{a_j}=\frac{1}{n}\sum_{i=1}^{n}u_{a_{ij}} \qquad (3)$$

$$\bar{v}_{a_j} = \frac{1}{n}\sum_{i=1}^{n} v_{a_{ij}} \qquad (4)$$

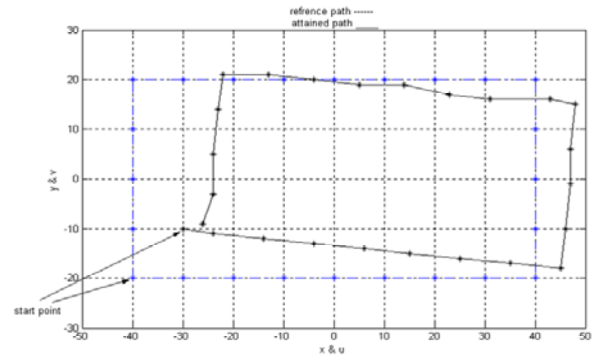

Fig. 5 Diagram of rectangular tests of robot (per pixel)

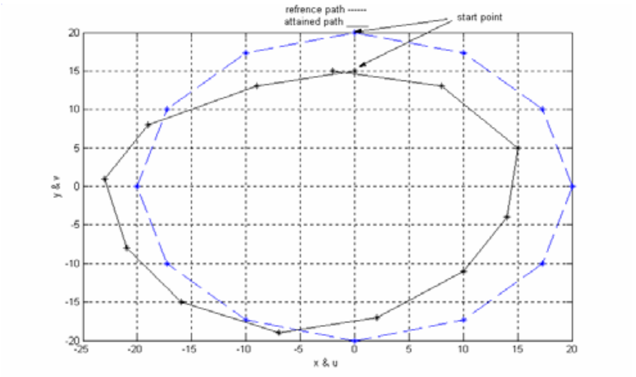

Fig. 6 Diagram of circle tests of robot (per pixel)

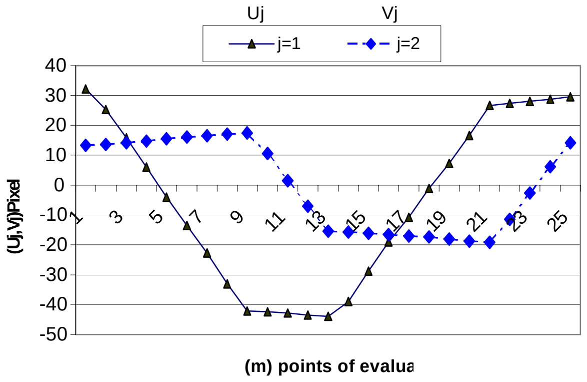

Fig. 7 Diagram of mean of U, V for each evaluation points on the rectangular paths for 10

So you can see diagram of result of U and V of the experiment about rectangular paths for 10 times in Fig. 7 by using equations 5-3 and 5-4.

Similarly, the diagram of result of U and V of the experiment about circle paths for 10 times are shown in Fig. 8.

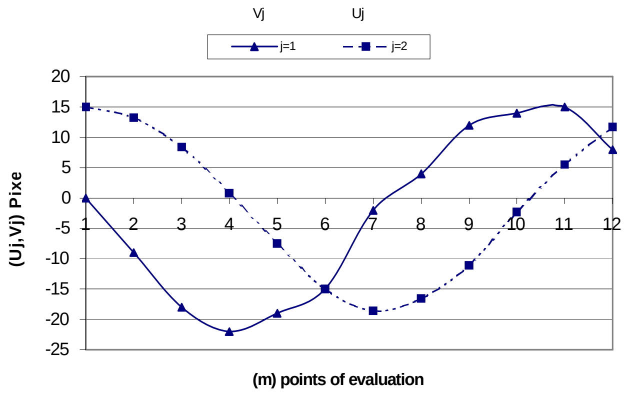

Fig. 8 Diagram of mean of U and V for each

XVI. PATH REPEATABILITY

Path repeatability is a measure of the closeness between multiple attained paths. Path repeatability may be evaluated using the same test procedure as used for relative path accuracy.

XVII. FOM CALCULATION OF PATH REPEATABILITY

The path repeatability FOM is evaluated as a scale value and represents the magnitude of the deviations. Path repeatability is identifiable as a value and it exposes the deviation in given evaluation plane. These deviations are obtained by the intersection of the n attained paths with the evaluation plane. Common parts are denoted by two dimensional coordinates (u, v). The mean reference path is used in the evaluation of the path repeatability FOM. This process involves the calculation of the deviation of D_{ij} between an evaluated point and its corresponding barycenter point.

$$D_{ij} = \sqrt{(u_{a_{ij}} - \bar{u}_{a_j})^2 + (v_{a_{ij}} - \bar{v}_{a_j})^2} \qquad (5)$$

$$PR = \max_{j=1}^{m} \max_{i=1}^{n} D_{ij} \qquad (6)$$

$$\overline{PR} = \max_{j=1}^{m} \frac{1}{n}\sum_{i=1}^{n} D_{ij} \qquad (7)$$

where, D_{ij} is the path deviance, PR is the maximum path repeatability and $\overline{PR}$ is average of path repeatability.

XVIII. CORNERING ROUND-OFF ERRORS

Cornering round off CR is defined as the minimum distance between the corner point and any point on the attained path. For each of the three corner points, the value for CR is calculated as follows:

$$CR = \min_{k=1}^{k} \sqrt{(X_e - X_{a_k})^2 + (Y_e - Y_{a_k})^2 + (Z_e - Z_{a_k})^2} \qquad (8)$$

where Xe,Ye, Ze are the position coordinates for each of the reference corner points and X_{ak}, Y_{ak}, Z_{ak}, are the coordinate of points along the attained path.

XIX. CORNERING OVERSHOOT

Cornering overshoot CO is defined as the largest deviation outside of the reference path after the robot has passed the corner. Its value is the maximum distance between the reference path and the attained path. The distance is determined in a plane perpendicular to a straight line between two adjacent reference points, and is calculated as:

$$CO = \max_{k=1}^{k} \sqrt{(X_e - X_{a_k})^2 + (Y_e - Y_{a_k})^2 + (Z_e - Z_{a_k})^2} \qquad (9)$$

where X_{ak}, Y_{ak} and Z_{ak} are the position coordinates for discrete data points on the attained path. X_{rk}, Y_{rk} and Z_{rk} are the coordinates of the sample data points along reference path.

After performing concerned tests, result in Tables I and II are obtained. Results show that the error on rectangle path is ascending. Most of errors are related to x axis that its mechanical movement system is weaker than the others. It should be noted that the results of these tests are influenced by not only robot's mechanic or hardware, but also by controlling software.

TABLE I
RESULT OF PATH-RELATED PARAMETERS

	Rectangular path	**Circle path**
AC	20.0998	8
$\overline{AC}$	11.8209	0
PR	7.3055	5.5009
$\overline{PR}$	3.5495	1.6180

TABLE II
RESULTS OF CORNER ERRORS AND CORNER OVERSHOOT IN RECTANGULAR REFERENCE PATH

	XX. R1	**R2**	**R3**
XXI. CR	18	5	5.385
XXII. CO	32.2	9.84	35.9

XX. CONCLUSION

In this article, it is shown how to use a vision system to control a 3P Cartesian robot. It was observed that before using this vision system for controlling a robot, we are in needs of general required information of the robot and the camera function and affects of light conditions on taken photos must be known. We can assume these results from the system as a better and more accurate control on robot around. In this system there is no need to know the first location of robot to calculate the required movement toward the goal, because taken images will help us to know the distance of the object to the end effector and this is one of the advantages of this system.

Vision system can be used for path-related characteristics of robot. In this article, by applying vision system, the path-related parameters are found for 3P Cartesian robot. The calculation of the path accuracy is simplified by finding the intersection of the attained path.

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